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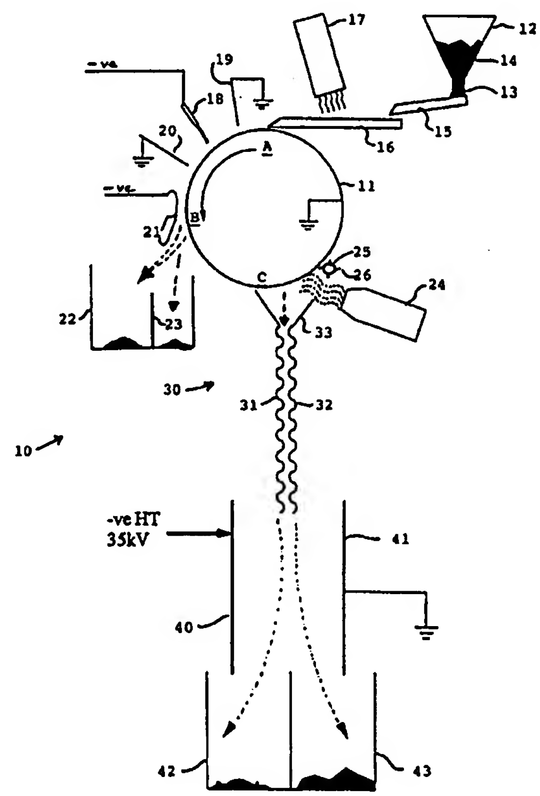
(54) Title: METHOD AND APPARATUS FOR SEPARATING PARTICLES

(57) Abstract

A method and apparatus for separating a mixture of particles carries out a first separation by using a separator (11, 18, 21) to separate those particles which lose an electrostatic charge relatively rapidly from those particles which lose an electrostatic charge relatively slowly. Those particles which lose charge relatively slowly are passed to charging apparatus (30) wherein the particles are charged. The particles are passed from the charging apparatus (30) to an electric field separator (40, 41) where a second separation is carried out wherein the charged particles are separated according to the charge adopted by said particles in the charging apparatus (30).



METHOD AND APPARATUS FOR SEPARATING PARTICLES

The present invention relates to a method and apparatus for separating particles.

There is an increasing demand to recover and recycle various materials from waste. Many materials can be successfully recovered and recycled. Such materials include metals and plastics for example.

When recovering materials from waste, it is usually desirable to separate the different types of material from each other. This is achieved in numerous ways, normally relying on the different physical properties of the materials.

In an established sorting and separating process, a hydrocyclone is used to separate different types of plastics according to differences in density of the different types of plastics. The material is cut into relatively small flakes and washed with detergent and water before being admitted to the hydrocyclone. Relatively low density polyolefins are removed as a light fraction of the waste by the hydrocyclone. A heavy fraction from the hydrocyclone contains plastics having a higher density such as PVC (polyvinyl chloride), PET (polyethylene terephthalate), PA (polyamide) and PC (polycarbonate) as well as other dense materials such as metals. This portion is often discarded because of the difficulties in separating these different materials.

The applicant has developed a new packaging material as described in WO-A-96/04120. This new packaging material is produced from a mixture of pulverulent propylene homopolymer or ethylene-propylene copolymer having a melt index according to ASTM of between 0.5 and 5 (230°C;2.16kg) and a filler such as chalk, talcum, mica, etc. preferably

having a particle size of between 1 and 30 μm and optionally other additives such as stabilisers, pigments, etc., which are mixed under conditions where the mixture is de-aired or evacuated at several points during the mixing process. The filler may be added in the amount of between 50% and 80%. Reference may be made to WO-A-96/04120, the entire disclosure of which is incorporated herein by reference, for further details on the material and how to make the material. This material will be referred to in this specification as " TPR" .

TPR is intended to be used widely for packaging food products and may be used for milk containers, for example. Although recovered TPR cannot be used again for food, it will have a variety of alternative applications. For example, recovered TPR can be used for the manufacture of underground pipes, though the purity of the recovered TPR must be very high.

TPR has a relatively high density and therefore forms part of the heavy fraction output from the conventional hydrocyclone process with mixed PVC, PET, PA, PC, etc.

There is therefore a need to provide an improved method and apparatus for separating particles, especially plastics particles. There is a particular need to be able to separate TPR from other plastics and preferably to do so in a manner such that the recovered TPR is extremely pure with little contamination from other materials.

A problem in separating materials output by the conventional hydrocyclone is that the materials are wet and usually contaminated by surfactants. It has been normal practice to dry thoroughly the output materials from the hydrocyclone because subsequent separation has been by an electrostatic sorting process for which very dry conditions have conventionally been required to prevent electric

charge leaking from the materials. The need to dry the materials output from the hydrocyclone significantly increases the complexity of the separating apparatus and increases the running costs due to the need for heaters, etc.

In US-A-5289922, there is disclosed a method of separating a mixture of plastics. The particles of the plastics mixture are tribocharged in a rotating tube which is preferably of the same material as a minority of the plastics particles. The tribocharged particles are then allowed to fall between charged plates to separate the particles according to their charge.

In DE-A-19522147, there is disclosed an electrostatic sorter for separating mixed particles of similar plastics into individual portions. Particles pass from a hopper to a vibrating platform from where they pass into a rotating tube. In the rotating tube, the particles become tribocharged to opposite polarities according to the type of material of the particles. The charged particles pass from the rotating tube to a further vibrating platform from where the particles pass to the outer surface of a rotating insulating roller. The roller contains an internal electrode of a first polarity and an external electrode of the opposite polarity. The particles therefore separate according to the polarity of their charge as the roller rotates, the internal electrode holding the particles of the appropriate charge polarity to the roller surface. In an actual embodiment which is marketed by the proprietor of DE-A-19522147, the drum has a diameter of 320mm and a relatively high rate of rotation of between 30 and 200 rpm. The high rate of rotation increases the running costs and also means that separation on one pass is not very satisfactory and repeated passes through the apparatus may be required in order to achieve satisfactory separation. Further, because the charging of the particles is achieved

by tribocharging, it is necessary for the particles to be dry before they are passed to the tribocharging apparatus and hot air is blown through the mixture of particles in the hopper for this purpose. This inevitably increases the capital costs and running costs of the equipment disclosed in DE-A-19522147.

Accordingly, there is a need for an improved separation method and apparatus which allows satisfactory separation on one pass. There is also a need for an improved separation method and apparatus which does not require the mixture to be separated to be dry.

According to a first aspect of the present invention, there is provided a method of separating a mixture of particles, the method comprising the steps of:

carrying out a first separation by separating those particles which lose an electrostatic charge relatively rapidly from those particles which lose an electrostatic charge relatively slowly;

passing those particles which lose charge relatively slowly to charging apparatus wherein the particles are charged; and,

passing the particles from the charging apparatus to an electric field separator for carrying out a second separation wherein said charged particles are separated according to the charge adopted by said particles in the charging apparatus.

The present invention provides excellent separation of the components of the mixture. In particular, the invention provides for very pure recovery of materials and with a high yield. The invention has particular applicability for recovering the TPR material mentioned above in a pure form from a mixture of materials.

The first separation may be carried out by applying an electric charge to the mixture to charge at least the electrically insulating particles of the mixture and retaining those particles which lose an electrostatic charge relatively slowly whilst removing those particles which lose an electrostatic charge relatively rapidly.

In the first separation, the mixture may be passed to a surface before said step of applying an electric charge to the mixture; and, those particles which lose charge relatively rapidly are allowed to lose their charge and are removed, the particles which lose charge relatively slowly being retained by the surface. The charged particles may be attracted to said surface by image force, said surface being a conductor.

In a preferred embodiment, the surface is the outer surface of a rotating drum. The rate of rotation of the drum may be less than 10 rpm. In a most preferred embodiment, the rate of rotation of the drum is about 4 rpm. This low rate of rotation reduces running costs as well as ensuring very good separation of the different components of the mixture, and therefore a high yield, because particles can be carefully placed on the drum surface and high charge given to the particles in situ on the drum surface.

The particles are preferably placed on said surface substantially without overlap of the particles such that each particle is in direct contact with said surface. This further ensures that each charged particle can be strongly attracted to the surface, ensuring a good yield of the material to be recovered.

The electric charge may be applied in the first separation by a single polarity corona discharge device.

As an alternative, the electric charge may be applied in the first separation by induction charging.

A charged electrode can be used to remove any conductive particles in the mixture. This allows materials such as metal foils to be removed in a simple and effective manner.

Said charging apparatus is preferably tribocharging apparatus and the method preferably comprises the step of tribocharging the particles to adopt different electric charge by causing said particles to rub over each other in the tribocharging apparatus, the tribocharged particles being separated in the second separation according to the polarity of their charge.

Preferably, the method comprises the step of eliminating any charge from those particles passing to the tribocharging apparatus prior to entry of said particles into the tribocharging apparatus.

Preferably, the particles are dried prior to entry of said particles into the tribocharging apparatus.

The tribocharging apparatus may comprise a channel along which particles pass, the channel having a wall across the path of the particles over which the particles flow. The channel is preferably vibrated to agitate the particles as the particles pass down the channel. The wall helps to ensure thorough mixing and therefore strong tribocharging of the particles.

As an alternative, the tribocharging apparatus may comprise vertically arranged opposed plates having surface projections over which the particles pass. The surface projections may be provided by corrugations of the opposed

plates. This simpler apparatus incurs practically no running costs.

The particles are preferably passed from the tribocharging apparatus to the electric field separator by a conveyor belt. The conveyor belt helps to ensure that the particles are distributed to the electric field separator individually and without sideways velocity.

According to a second aspect of the present invention, there is provided apparatus for separating a mixture of particles, the apparatus comprising:

means for carrying out a first separation by separating those particles which lose an electrostatic charge relatively rapidly from those particles which lose an electrostatic charge relatively slowly;

charging apparatus for receiving from the first separation means those particles which lose charge relatively slowly and for charging said particles; and,

an electric field separator for receiving the particles from the charging apparatus for carrying out a second separation wherein said charged particles are separated according to the charge adopted by the particles in the charging apparatus.

The first separation means preferably comprises means for applying an electric charge to the mixture to charge at least the electrically insulating particles of the mixture and an image force separator having a surface to which the charged particles are attracted. Said surface of the image force separator may be an outer surface of a rotating drum.

The means for applying an electric charge to the mixture may comprise a single polarity corona discharge device. As an alternative, the means for applying an electric charge to the mixture may comprise an induction charging device.

A charged electrode may be provided for removing any conductive particles in the mixture.

Said charging apparatus preferably comprises tribocharging apparatus for tribocharging the particles.

A static charge eliminator is preferably provided for eliminating any charge from those particles passing to the tribocharging apparatus prior to entry of said particles into the tribocharging apparatus.

The tribocharging apparatus may comprises a channel along which particles pass, the channel having a wall across the path of the particles over which the particles flow. Means are preferably provided for vibrating the channel to agitate the particles as the particles pass down the channel.

The tribocharging apparatus may alternatively comprise vertically arranged opposed plates having surface projections over which the particles pass. The surface projections may be provided by corrugations of the opposed plates.

A conveyor belt is preferably provided for passing the particles from the tribocharging apparatus to the electric field separator. The conveyor belt preferably has a radiussed end positioned over the electric field separator. The radiussed end of the conveyor belt ensures that an intense electric field is generated at the end of the conveyor belt.

According to a third aspect of the present invention, there is provided a method of separating a mixture of particles, the method comprising the steps of:

applying an electric charge to the mixture to charge at least the electrically insulating particles of the mixture;

carrying out a separation using image force separation by passing the mixture to an outer surface of a rotating drum to separate those charged particles which lose charge relatively rapidly from those charged particles which lose charge relatively slowly, the rate of rotation of the drum being less than about 10 rpm.

In a preferred embodiment, the rate of rotation of the drum is about 4 rpm. This low rate of rotation reduces running costs as well as ensuring very good separation of the different components of the mixture and therefore a high yield.

The particles are preferably placed on said outer surface of said drum substantially without overlap of the particles such that each particle is in direct contact with said surface. This further ensures that each charged particle can be strongly attracted to the surface, ensuring a good yield of the material to be recovered.

According to a fourth aspect of the present invention, there is provided apparatus for separating a mixture of particles, the apparatus comprising:

tribocharging apparatus in which different particles adopt different electrical charges by rubbing over each other;

a conveyor belt for receiving the charged particles from the tribocharging apparatus; and,

an electric field separator for receiving the particles conveyed by the conveyor belt from the tribocharging apparatus for carrying out a separation wherein said tribocharged particles are separated according to their charge.

The conveyor belt preferably comprises a radiussed end positioned over the electric field separator. The electric field generated by the electric field separator is particularly intense in the region of the end of the belt. This helps to ensure that the charged particles leaving the belt are properly and completely separated by the electric field separator.

Embodiments of the present invention will now be described by way of example with reference to the accompanying drawings, in which:

Fig. 1 is a schematic representation of the build up of image charges when an insulator is brought into contact with a conductor;

Fig. 2 is a schematic side elevation of an example of apparatus according to one aspect of the present invention;

Fig. 3 is a schematic side elevation of a variation of a portion of the apparatus shown in Figure 2; and,

Fig. 4 is a schematic side elevation of a further variation of a portion of the apparatus shown in Figure 2.

When an insulating material, such as a polymer, has been processed in an atmosphere of high humidity, the surface conductivity of the material usually increases. This is due to adsorption of water molecules and the effect can be particularly pronounced if the surface of the material has been contaminated by surfactants. Accordingly, at high humidity, most polymers in contact with earth will not hold a charge for more than a few seconds.

It has been found that, surprisingly, the material TPR described above and in WO-A-96/04120 holds its surface

charge at high humidity for a long time. This is true even if the TPR is coated with surface contaminants. For example, in an experiment to measure the charge decay times of various plastics at 75% relative humidity, the charge decay time for PET was 15 seconds whereas the charge decay time for TPR was 15.6 hours. Other plastics such as PVC typically had charge decay times of 10 seconds. The reasons for the very long charge decay time for TPR are not presently fully understood, but it is believed to be because the TPR material tends to lose surface contaminants, possibly due to a hydrophobic property of the material. This feature allows the TPR material to be separated using electrostatic methods without requiring the TPR to be absolutely dry and without requiring the separation process to be carried out in controlled low humidity environments. Indeed, separation of the TPR material from other plastics in a mixture is facilitated in the present invention by wetting the mixture and then removing excess water prior to separation of the components of the mixture.

In a first stage of one example of a separation process in accordance with the present invention, electrostatic separation using image force separation is utilised.

As indicated in Figure 1, if a charged insulator 1 is brought into contact with an earthed conductor such as a metal plate 2, electric charges 3 of opposite sign to the electric charges 4 on the insulator 1 are induced in the metal plate at the boundary between the insulator 1 and the metal plate 2. These opposite charges 3,4 provide an " image force" which tends to cause the insulator 1 to stick to the metal plate 2. The maximum charge density which can be built up on the insulator 1 and metal plate 2 is dependent on the dielectric breakdown strength of the insulator 1 and is also a function of the distance between

the charged surface 5 of the insulator 1 and the metal plate 2, i.e. the thickness of the insulator 1. Thus, where the insulating material 1 has a high surface area to volume ratio (such as flakes rather than granules, for example), the insulating material tends to remain firmly attached to the metal plate 2. This is especially so where the insulating material 1 tends to hold its charge for a long time, which is the case for the material TPR. On the other hand, materials such as PET tend to lose their charge rapidly and can quickly become detached from the metal plate 2.

Accordingly, given the long charge decay times of wet TPR compared to the short charge decay times of other wet plastics especially when contaminated with surfactants, an efficient way of separating the TPR from other plastics or, more generally, other insulators, has been found to place individual flakes of the mixture of TPR and other plastics onto an earthed conductive surface and charge the flakes. It is desirable that practically all of the flakes be allowed to come into contact with the earthed conductive surface to ensure good attachment of the flakes to the conductive surface. It is preferred that the flakes be charged in situ on the conductive surface as the flakes can acquire a higher charge than if they were charged in space. This is because if the flakes are charged on a conductive surface, the electric field lines pass through the high dielectric material of the flakes from the charged surface of the flake to the underlying conductive surface. If a flake is charged in space, the field lines pass through air which has a low breakdown strength and which therefore limits the charge to a low level because dielectric breakdown of the air in the region of the flakes causes the flakes to lose charge.

Referring now to Figure 2, there is shown schematically an example of apparatus 10 for separating

mixtures of particles of different types. The apparatus 10 has several distinct sections.

In a first section, separation is carried out using image-force electrostatic separation. A cylindrical drum 11 of a conductive material such as metal is earthed and is oriented so that its central longitudinal axis is horizontal. The drum 11 is driven to rotate about its central longitudinal axis. In an example, the diameter of the drum 11 was 460mm and the rate of rotation was 4rpm. The rate of rotation is variable. Because the rate of rotation of the drum 11 is so slow (especially compared to the rate of rotation of the drum in the marketed embodiment of the apparatus disclosed in DE-A-19522147 as mentioned above), running costs are much reduced and good separation is achieved.

The wet heavy fraction output from a hydrocyclone, which mainly contains TPR and PET and usually smaller amounts of PVC and the other high density plastics and materials such as metals, all in the form of flakes typically having a flat surface and a nominal thickness of less than 3mm, is conditioned by removing surplus water. It should be noted here that thorough drying of the heavy fraction from the hydrocyclone is not required, in contrast to prior art processes, and indeed it is preferred that the particles be damp at this stage. This can be achieved by spinning the wet output from a hydrocyclone in a centrifugal spinner for 15 minutes to remove excess water to leave damp flakes. Furthermore, the separating apparatus does not have to be enclosed within a humidity-controlled environment and the whole process can take place at ambient humidity, for example.

This conditioned heavy fraction, from which surplus water has been removed, is passed to a vibratory hopper 12. The hopper 12 has a rectangular exit 13 the size of which

can be adjusted to control the rate of flow of material 14 out of the hopper 12. The amplitude of vibration of the vibratory hopper 12 is adjustable.

The output 13 from the hopper 12 feeds material 14 down a chute 15 to a delivery tray 16 which slopes downwards slightly. The delivery tray 16 is driven to reciprocate laterally (i.e. generally horizontally and transverse to the direction of flow of the material 14 down the tray 16) so that the material 14 is encouraged to slide down the shallow incline of the delivery tray 16 and so that the individual flakes of the mixture are scattered across the tray 16. A hot air heater 17 may be used to blow hot air onto the delivery tray 16 and its output controlled to provide some drying of the damp flake material 14 and also to prevent condensation from forming on the tray 16 which may otherwise cause the flakes 14 to stick to the tray 16. Alternatively or additionally, the delivery tray 16 may include a heater to keep its surface warm and dry.

The reciprocating delivery tray 16 delivers flakes 14 to the outer surface of the rotating drum 11 at the uppermost portion A of the drum 11. The delivery rate is matched to the rotational speed of the drum 11 so that the flakes 14 are placed on the surface of the drum 11 individually and substantially without overlap of the particles to ensure that each particle is in direct contact with the drum 11. This careful placement of the particles on the surface of the drum 11, especially when combined with the low rate of rotation of the drum 11, also ensures that the highest possible charge is given to each particle. This ensures that good separation is achieved by this stage and it is not necessary to repeat the process for a particular sample in order to achieve satisfactory separation.

As the drum 11 rotates, the particles on the outer surface of the drum 11 pass under a single polarity corona discharge device such as a corona brush 18 which is connected to a supply of high negative voltage of, for example, -15kV. The corona brush 18 is placed at a position which is at an angle of about 30° to 45° from vertical as measured at the centre of the drum 11. The gap from the tip of the bristles of the corona brush 18 to the outer surface of the drum 12 is 40mm. The corona brush 18 charges particles as they pass under the brush 18. The charged particles tend to become attached to the outer surface of the drum 11 by means of the generated image force described above. An earthed metal screen 19,20 is positioned on either side of the corona brush 18 in the direction of travel of the drum 11 to prevent the corona brush 18 charging particles whilst still on the delivery tray 16 (which would otherwise cause the particles to become attached to the tray 16) and to prevent the corona brush 18 affecting the separation process downstream of the brush 18.

A secondary separation electrode 21 is positioned close to the outer surface of the drum 11 downstream of the corona brush 18 and the second earthed screen 20. The secondary separation electrode 21 is connected to a source of high negative voltage. The secondary separation electrode 21 is shaped so that it diverges or curves away from the drum 11 in the direction of rotation of the drum 11 as indicated in Figure 2. The secondary separation electrode 21 charges by induction those particles which are relatively more electrically conducting. This induced charge causes the more conductive particles to be attracted to the secondary separation electrode 21 and therefore to jump from the outer surface of the drum 11. A collection box 22 is positioned to catch those particles which jump from the drum 11. Such particles include PET, paper and metal foil, all of which are relatively more conductive

than the insulators which remain firmly attached to the drum 11. In the specific application of the apparatus of Figurer 2 where it is desired to recover substantially pure TPR, it is not a concern if some TPR is lost into the collection box 22. Accordingly, in the preferred embodiment, the voltage applied to the secondary separation electrode 21 should be high enough to ensure that substantially all of the more conductive particles such as PET, paper and foil are pulled off the drum 11. It has been found that a relatively large secondary separation electrode 21 tends to force TPR particles more strongly against the drum 11 and also tends to cause PET particles to lose their charge more rapidly; both of these are desirable effects.

Because of the relatively low rate of rotation of the drum 11, those insulative particles which rapidly lose their surface charge will have lost substantially all of their surface charge by the time that they pass the vertical position B of the drum 11. Accordingly, those insulative particles which lose their surface charge rapidly will tend to fall from the drum 11 as they pass the position B and they can also be collected in the collection box 22. The collection box 22 can be divided by a dividing wall 23 to keep separate the particles of different types.

Accordingly, those particles which remain attached to the outer surface of the drum 11 as they reach the underneath of the drum 11 at position C tend to be insulative particles which maintain their surface charge for a relatively long time. Such particles will predominantly be TPR in the specific example described herein.

The charged insulative particles which remain attached to the drum 11 as they reach the underneath position C of the drum 11 are discharged by using a static eliminator 24.

In the example shown, the static eliminator 24 is a heated volume static eliminator. Alternatively, an a.c. corona static eliminating bar may be directed at the surface of the drum 11 to discharge the particles and aid their detachment from the drum 11 as the air flow from a heated volume static eliminator may cause scattering of the particles. In any event, the discharged particles fall from the surface of the drum 11. A counter-rotating roller 25 having four " Dralon" (trade mark) cloth blades 26 may be positioned after the static eliminator 24 to sweep any remaining particles from the surface of the drum 11.

The discharged particles falling from the underneath surface of the drum 11 pass into a tribocharging apparatus 30. It has been found that the discharged particles falling from the underneath surface of the drum 11 are almost exclusively TPR and PET when a typical heavy fraction output from a hydrocyclone is introduced into the apparatus 10, other materials having been collected in the collection box 22. The falling particles may be subjected to a flow of hot air to provide some drying of the particles prior to entry into the tribocharging apparatus 30 as the particles would typically still be damp on leaving the surface of the drum 11. A first example of tribocharging apparatus 30 is shown in Figure 2 and a second example of tribocharging apparatus 30 is shown in Figure 3.

When two different materials are rubbed over each other, an exchange of electrons takes place at the interface due to a difference in the work functions of the materials, this process being known as tribocharging. If one or both of the materials is an insulator, then the two materials retain their respective equal and opposite charges when the materials are separated. Various triboelectric series have been published which list in order various materials, the order in the list being such

that each material charges positively relative to all materials below it in the list. In practice, varying degrees of charge are often observed on materials if their surfaces are contaminated by residues. The ambient humidity can also have an effect on the degree of tribocharging. Nevertheless, it is a feature of tribocharging that all pieces of one material in a binary mixture usually charge to a single polarity whilst all of the pieces of the other material usually charge to the opposite polarity.

In the example shown in Figure 2, the tribocharging apparatus 30 has two vertically orientated corrugated sheets 31,32. The sheets 31,32 in one example were made from plasticised PVC. However, in some circumstances, earthed conductive sheets 31,32 such as of metal may be preferred in order to prevent a build up of charge on the sheets 31,32. The sheets 31,32 are positioned close together in order to slow down the passage of particles between the sheets 31,32 thereby to ensure vigorous mixing of the particles and therefore efficient tribocharging. A collection funnel 33 is provided below the drum 11 to direct particles into the space between the sheets 31,32. Further static eliminators (not shown) may be positioned between the collection funnel 33 and the tribocharging apparatus 30 to ensure that all particles are discharged before entry into the tribocharging apparatus 30.

The lower ends of the sheets 31,32 are positioned to discharge the charged particles between two oppositely charged plate electrodes 40,41. The plates 40,41 are positioned 200mm apart. One of the plates 40 may be held at a negative voltage of between 10kV and 150kV, with a preferred negative voltage of 35kV, and the other plate 41 may be earthed for example. Positively charged particles are attracted to the negative plate 40 and are therefore directed to a first collection box 42. Negatively charged

particles are repelled by the negatively charged electrode 40 and are directed to a second collection box 43. The collection boxes 42,43 are positioned below the plate electrodes 40,41.

Whilst the example of the tribocharging apparatus 30 shown in Figure 2 is very simple to manufacture and requires practically no maintenance, it was found that particles exiting the corrugated sheets 31,32 had sideways momentum which depended on the angle of the surface of the corrugated sheets 31,32 which was last contacted by the particles. This sideways momentum can be too great in some circumstances to allow proper deflection by the plate electrodes 40,41 to the correct collection box 42,43. Where very high purity of the recovered material is required, the tribocharging apparatus 30 shown in Figure 3 and described further below may be used. It was also found that the particles charged much more strongly to the required polarities when they rubbed against each other rather than against the material of the corrugated sheets 31,32. Accordingly, if the flow rate of particles through the corrugated sheets 31,32 is too low, too small a charge may develop on the particles to allow complete separation by the electrodes 40,41.

A more efficient tribocharging apparatus 30, which is more complex than the example shown in Figure 2 but which ensures more vigorous shaking of the particles, is shown in Figure 3.

In the example shown in Figure 3, the tribocharging apparatus has a first channel 50 having a generally U-shape cross-section having side walls (not shown) of height 30mm and a base of width 300mm. The first channel 50 slopes downwards and its uppermost end is mounted for pivotal movement about a fixed pivot point 51. The other, lowermost end 52 of the first channel 50 is connected to

one end of a connecting rod 53. The other end of the connecting rod 53 is eccentrically mounted on a motor-driven roller 54. Thus, as the roller 54 rotates, the second end 52 of the first channel 50 can move up and down about the pivot point 51.

The first channel 50 has plural transverse walls 55 along its length between the side walls. A lid 56 is provided over the first channel 50 to retain particles within the channel 50. A space is left between the top edges of the walls 55 and the lid 56 to allow particles to pass down the channel 50. It will be appreciated that the walls 55 detain particles within the channel 50 and the pivotal motion of the channel 50 ensures vigorous mixing of the particles as they travel down the channel 50.

A second channel 57 is pivotally connected to the lowermost end of the first channel 50 to allow further mixing of the particles to take place. The second channel 57 has a U-shape cross-section having side walls (not shown) and a base. The second channel 57 is " switched back" under the first channel 50 to save space. The second channel 57 has plural transverse walls 58 along its length and a lid 59 which are similar in construction and function to the transverse walls 55 and lid 56 of the first channel 50. The lowermost end of the second channel 57 has wheels 60 which allow the lowermost end of the second channel 57 to move back and forth as the first channel 50 is pivoted about the pivot point 51. The second channel 57 slopes downwards and has an exit 61 from which the particles, which have been charged by tribocharging during travel down the channels 50,57, pass and are directed between separating electrodes 40,41 as shown in Figure 2.

The channels 50,57 are made of a conductive material such as aluminium and are earthed. This prevents charge building up on the internal surfaces of the channels 50,57,

thereby preventing a time-dependent deterioration of performance of the tribocharging apparatus 30. An a.c. corona static charge eliminating bar may be directed at the flakes 14 falling onto the top plate of the first channel 50 to ensure that all flakes are electrically discharged before entering the tribocharging apparatus 30.

As a further alternative to the tribocharging apparatus 30 shown in Figures 2 and 3, a system of rotating pipes (similar to that disclosed in DE-A-19522147 or US-A-5289922) may be used.

In a preferred embodiment, regardless of the particular type of tribocharging apparatus 30 used, the output from the tribocharging apparatus 30 is passed to a conveyor belt 70 which conveys the charged particles to fall between the two oppositely charged plate electrodes 40,41, as indicated in Figure 4. The conveyor belt 70 has a variable speed. The speed of the conveyor belt 70 is adjusted so that the particles are evenly distributed on the conveyor belt 70 and may typically be driven with a maximum linear speed of 4m/min. The particles can then fall individually between the charged plate electrodes 40,41 which ensures that the particles are properly and completely separated by the charged plate electrodes 40,41. Further, the particles tend to leave the end 71 of the conveyor belt 70 with little or no sideways velocity (except as discussed below), again helping to ensure that the different types of particle are completely separated by the charged plate electrodes 40,41. The conveyor belt 70 is made of a material which is anti-static or treated to be anti-static.

Because the end 71 of the conveyor belt 70 (where the belt 70 turns under itself) is radiussed with a relatively small radius of 15mm, the electric field generated by the two charged plate electrodes 40,41 is particularly intense

in the region of the end 71 of the belt 70. This helps to ensure that the charged particles leaving the belt 70 are properly and completely separated by the charged plate electrodes 40,41.

The negative electrode 40 has an upper portion 40' which is at an angle of about 135° to the lower part of the negative electrode 40 and directed towards the end 71 of the conveyor belt 70. The angled portion 40' serves to create an intense electric field in the region of the end 71 of the belt 70. The angled portion 40' also ensures that the positively charged particles leaving the conveyor belt 70 which might be attracted towards the negative electrode 40 do not rebound off the negative electrode 40 into the collection box 43 which is intended to receive the negatively charged particles as the angled portion 40' instead directs any positively charged particles which strike the negative electrode 40 into the correct collection box 42. As the positively charged particles can jump from the conveyor belt 70 to the angled portion 40' of the negative electrode 40 and can become attached to that portion 40', a sheet 44 of insulating material, such as Perspex (trade mark), is placed 10mm in front of the angled portion 40' of the negative electrode 40 to prevent the positively charged particles becoming attached to that portion 40'.

In a trial of a prototype of the apparatus 10, a 1kg mixture of 2:1 TPR to a typical heavy fraction output from a hydrocyclone was prepared and conditioned by wetting with 1 litre of water and then spinning in a centrifugal spinner for 15 minutes to remove excess water. The conditioned mixture was then passed through the apparatus 10. The time taken to separate the 1 kg mixture in the (small scale) prototype was 10 minutes. The results were as follows:

Total polymer in:	1000g	
Total polymer out:	885g	
Loss from machine:	115g	
Reject from image force stage:	213g (24%))	
Reject from tribocharging stage:	157g (17%))	= 100%
TPR recovered	515g (58%))	
Purity of TPR by mass:	99.6%	
Yield of TPR	88%	

Thus, very pure TPR was recovered with a reasonably good yield. For the proposed application of the recovered TPR mentioned above, the requirements for extreme purity outweigh the need for a very high yield. A good yield is achieved on one pass through the apparatus. Moreover, repeated trials using different ratios of TPR flakes to other materials produced similarly excellent purity and high yield.

The apparatus 10, especially the first section using image force separation and the secondary electrode 21, is extremely tolerant of variations in moisture content of the input particles, different proportions of the input mixture, and inclusions of materials other than plastics such as paper or metal foil. The apparatus can be inexpensively manufactured. Operating costs should be low, especially as the rate of rotation of the drum is low thereby requiring only relatively low power input. The apparatus should be simple and inexpensive to maintain. The separation process can be substantially continuous.

A throughput of material of 350kg/hour can be achieved with a drum width of approximately 2.5 metres and the drum diameter of 460mm mentioned above.

Whilst separation using tribocharging and field plates can in itself produce good separation of the materials, the

combination of the image force separation and the tribocharging and electric field separation in accordance with one aspect of the present invention provides for recovery of extremely pure TPR material. The image force separation stage, using the rotating drum 11 and corona brush 18 together with the secondary separation electrode 21, tends to discard many unwanted inclusions, especially the more conductive items such as metal foils and polyesters.

In summary, the preferred embodiment of the present invention uses the following sequence of operations:

1. Flake conditioning (including wetting and removal of excess water);
2. Individual positioning of flakes on the surface of the drum;
3. Corona charging of the flakes on the surface of the drum;
4. Image force separation;
5. Discharging of electrical charge of flakes remaining in the drum;
6. Flake reconditioning (including drying);
7. Tribocharging;
8. Control of flake delivery from the tribocharging apparatus to the electrical field separator; and,
9. Electrical field separation.

An embodiment of the present invention has been described with particular reference to the examples illustrated. However, it will be appreciated that variations and modifications may be made to the examples described within the scope of the present invention. For example, the vibratory hopper 12 may be replaced by an alternative feed mechanism such as a helical screw auger. Helical screw augers may also be used to empty the collection boxes 22,42,43.

CLAIMS

1. A method of separating a mixture of particles, the method comprising the steps of:

carrying out a first separation by separating those particles which lose an electrostatic charge relatively rapidly from those particles which lose an electrostatic charge relatively slowly;

passing those particles which lose charge relatively slowly to charging apparatus wherein the particles are charged; and,

passing the particles from the charging apparatus to an electric field separator for carrying out a second separation wherein said charged particles are separated according to the charge adopted by said particles in the charging apparatus.

2. A method according to claim 1, wherein the first separation is carried out by applying an electric charge to the mixture to charge at least the electrically insulating particles of the mixture and retaining those particles which lose an electrostatic charge relatively slowly whilst removing those particles which lose an electrostatic charge relatively rapidly.

3. A method according to claim 2, comprising the steps of, in the first separation, passing the mixture to a surface before said step of applying an electric charge to the mixture; carrying out said step of applying an electric charge to the mixture; and, allowing those particles which lose charge relatively rapidly to lose their charge and removing said particles, the particles which lose charge relatively slowly being retained by the surface.

4. A method according to 3, wherein the charged particles are attracted to said surface by image force, said surface being a conductor.

5. A method according to claim 3 or claim 4, wherein the surface is the outer surface of a rotating drum.

6. A method according to claim 5, wherein the rate of rotation of the drum is less than about 10 rpm.

7. A method according to claim 6, wherein the rate of rotation of the drum is about 4 rpm.

8. A method according to any of claims 3 to 7, wherein the particles are placed on said surface substantially without overlap of the particles such that each particle is in direct contact with said surface.

9. A method according to any of claims 2 to 8, wherein the electric charge is applied in the first separation by a single polarity corona discharge device.

10. A method according to any of claims 2 to 8, wherein the electric charge is applied in the first separation by induction charging.

11. A method according to any of claims 1 to 10, wherein a charged electrode is used to remove any conductive particles in the mixture.

12. A method according to any of claims 1 to 11, wherein said charging apparatus is tribocharging apparatus and comprising the step of tribocharging the particles to adopt different electric charge by causing said particles to rub over each other in the tribocharging apparatus, the tribocharged particles being separated in the second separation according to the polarity of their charge.

13. A method according to claim 12, comprising the step of eliminating any charge from those particles passing to the

tribocharging apparatus prior to entry of said particles into the tribocharging apparatus.

14. A method according to claim 12 or claim 13, wherein the particles are dried prior to entry of said particles into the tribocharging apparatus.

15. A method according to any of claims 12 to 14, wherein the tribocharging apparatus comprises a channel along which particles pass, the channel having a wall across the path of the particles over which the particles flow.

16. A method according to claim 15, wherein the channel is vibrated to agitate the particles as the particles pass down the channel.

17. A method according to any of claims 12 to 14, wherein the tribocharging apparatus comprises vertically arranged opposed plates having surface projections over which the particles pass.

18. A method according to claim 17, wherein the surface projections are provided by corrugations of the opposed plates.

19. A method according to any of claims 12 to 18, wherein the particles are passed from the tribocharging apparatus to the electric field separator by a conveyor belt.

20. Apparatus for separating a mixture of particles, the apparatus comprising:

means for carrying out a first separation by separating those particles which lose an electrostatic charge relatively rapidly from those particles which lose an electrostatic charge relatively slowly;

charging apparatus for receiving from the first separation means those particles which lose charge relatively slowly and for charging said particles; and,

an electric field separator for receiving the particles from the charging apparatus for carrying out a second separation wherein said charged particles are separated according to the charge adopted by the particles in the charging apparatus.

21. Apparatus according to claim 20, wherein the first separation means comprises means for applying an electric charge to the mixture to charge at least the electrically insulating particles of the mixture and an image force separator having a surface to which the charged particles are attracted.

22. Apparatus according to claim 21, wherein said surface of the image force separator is an outer surface of a rotating drum.

23. Apparatus according to claim 21 or claim 22, wherein the means for applying an electric charge to the mixture comprises a single polarity corona discharge device.

24. Apparatus according to claim 21 or claim 22, wherein the means for applying an electric charge to the mixture comprises an induction charging device.

25. Apparatus according to any of claims 20 to 24, comprising a charged electrode for removing any conductive particles in the mixture.

26. Apparatus according to any of claims 20 to 25, wherein said charging apparatus comprises tribocharging apparatus for tribocharging the particles.

27. Apparatus according to claim 26, comprising a static charge eliminator for eliminating any charge from those particles passing to the tribocharging apparatus prior to entry of said particles into the tribocharging apparatus.

28. Apparatus according to claim 26 or claim 27, wherein the tribocharging apparatus comprises a channel along which particles pass, the channel having a wall across the path of the particles over which the particles flow.

29. Apparatus according to claim 28, comprising means for vibrating the channel to agitate the particles as the particles pass down the channel.

30. Apparatus according to claim 26 or claim 27, wherein the tribocharging apparatus comprises vertically arranged opposed plates having surface projections over which the particles pass.

31. Apparatus according to claim 30, wherein the surface projections are provided by corrugations of the opposed plates.

32. Apparatus according to any of claims 26 to 31, comprising a conveyor belt for passing the particles from the tribocharging apparatus to the electric field separator.

33. Apparatus according to claim 32, wherein the conveyor belt comprises a radiussed end positioned over the electric field separator.

34. A method of separating a mixture of particles, the method comprising the steps of:

applying an electric charge to the mixture to charge at least the electrically insulating particles of the mixture;

carrying out a separation using image force separation by passing the mixture to an outer surface of a rotating drum to separate those charged particles which lose charge relatively rapidly from those charged particles which lose charge relatively slowly, the rate of rotation of the drum being less than about 10 rpm.

35. A method according to claim 34, wherein the rate of rotation of the drum is about 4 rpm.

36. A method according to claim 34 or claim 35, wherein the particles are placed on said outer surface of said drum substantially without overlap of the particles such that each particle is in direct contact with said surface.

37. Apparatus for separating a mixture of particles, the apparatus comprising:

tribocharging apparatus in which different particles adopt different electrical charges by rubbing over each other;

a conveyor belt for receiving the charged particles from the tribocharging apparatus; and,

an electric field separator for receiving the particles conveyed by the conveyor belt from the tribocharging apparatus for carrying out a separation wherein said tribocharged particles are separated according to their charge.

38. Apparatus according to claim 37, wherein the conveyor belt comprises a radiussed end positioned over the electric field separator.

39. A method of separating a mixture of particles, substantially as described with reference to any of the examples shown in the accompanying drawings.

40. Apparatus for separating a mixture of particles, substantially as described with reference to any of the examples shown in the accompanying drawings.

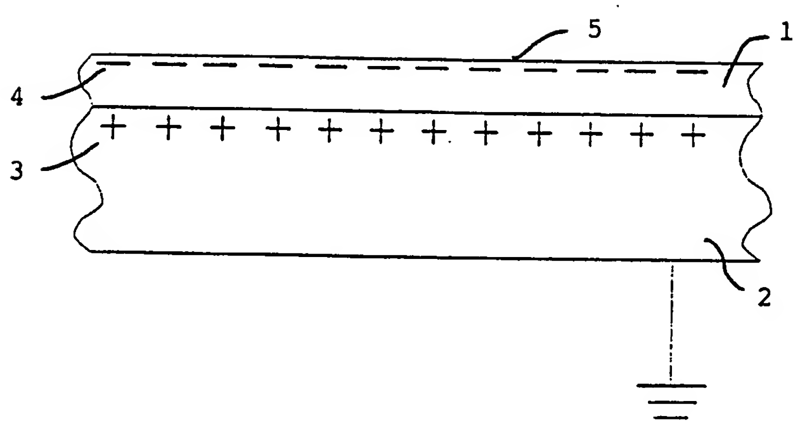


FIG. 1

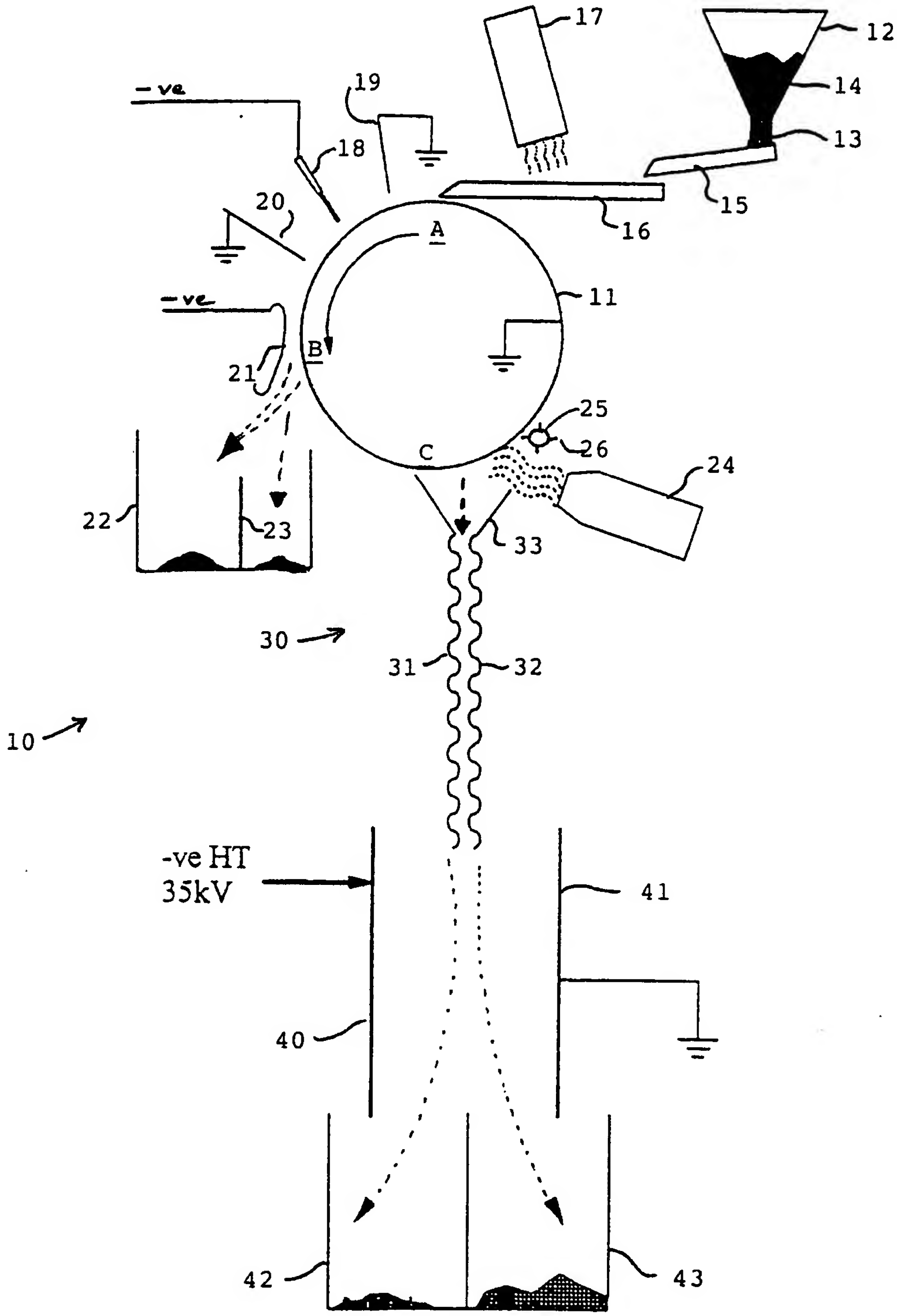

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FIG.2

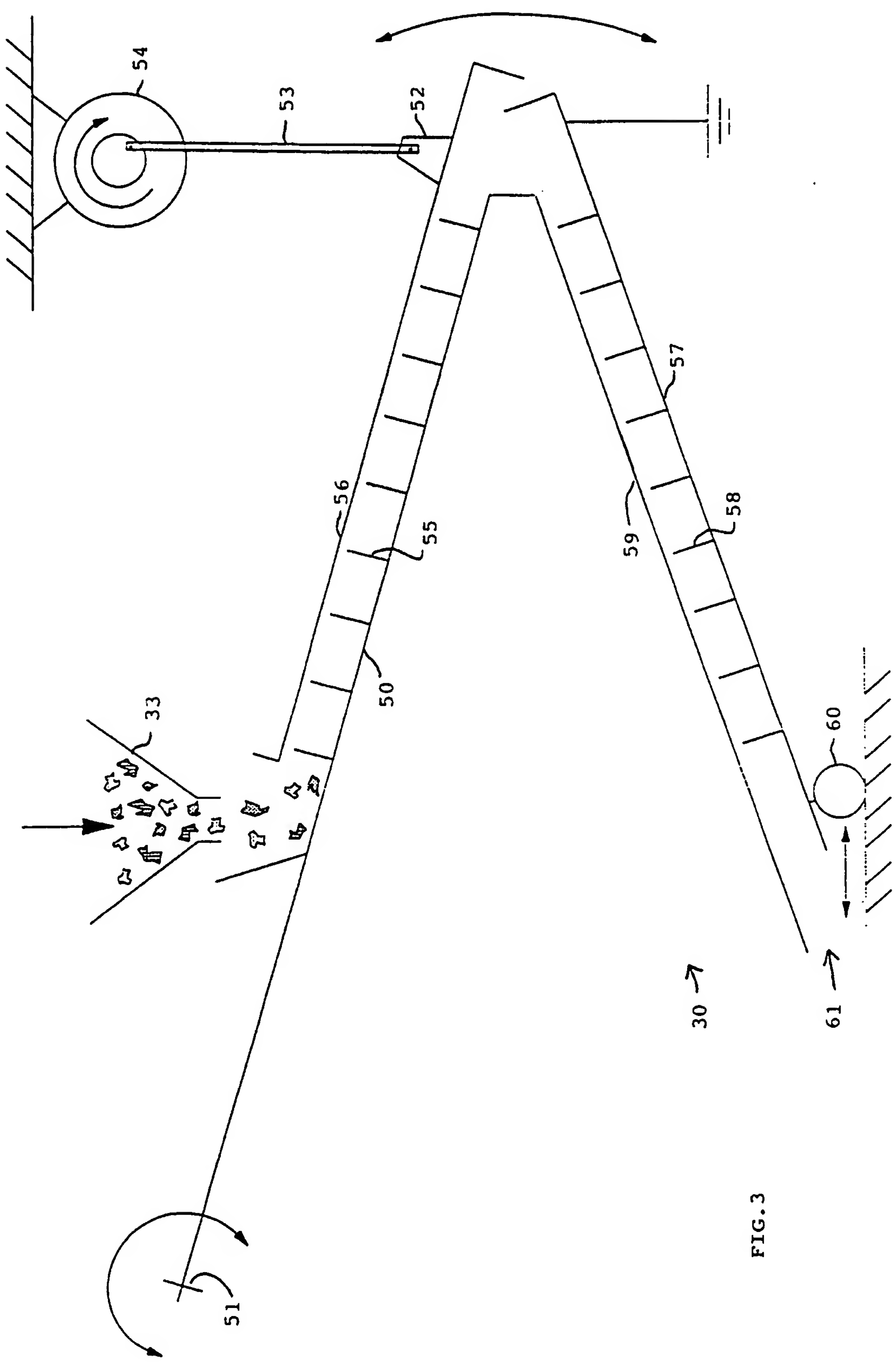

FIG.3

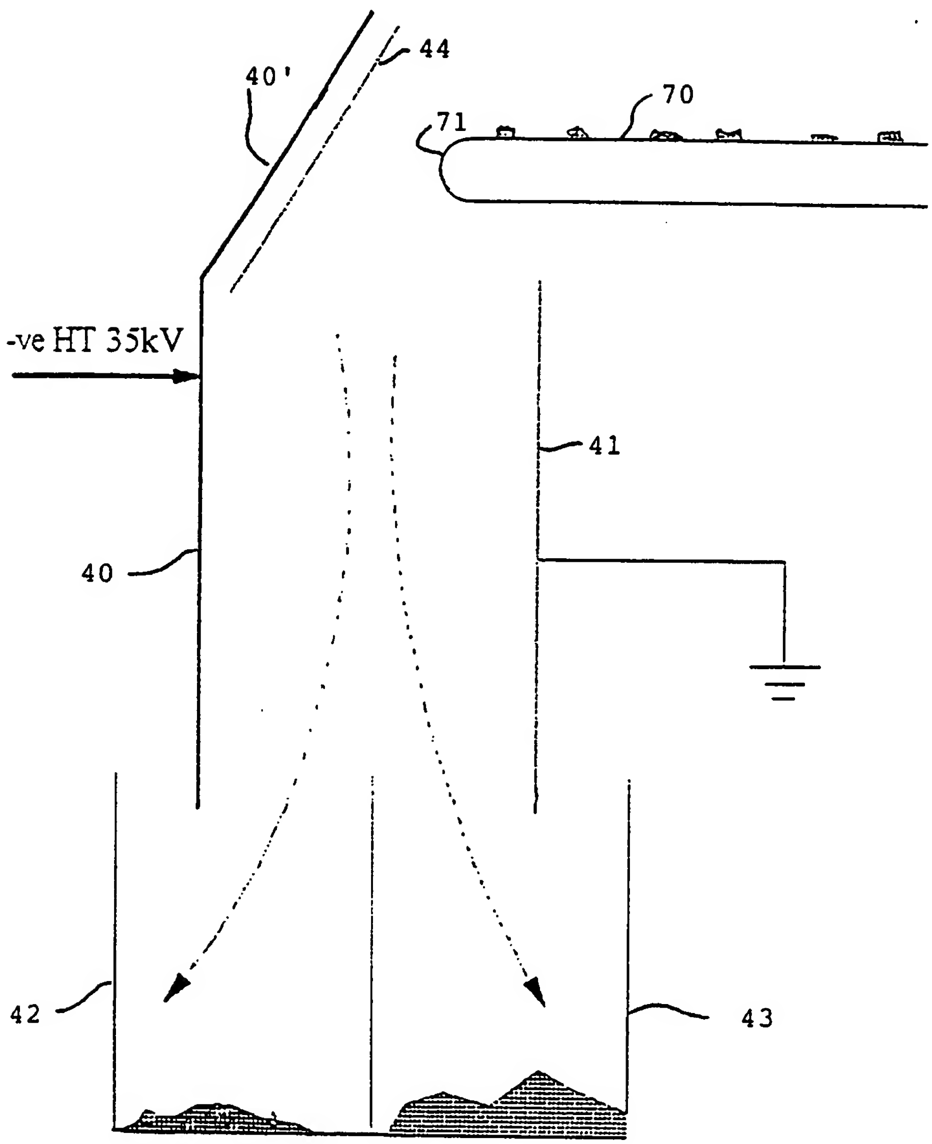

FIG.4

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 98/03670

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 B03C7/00 B03C7/06

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 B03C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DE 42 25 977 C (KALI & SALZ AG) 27 January 1994 see claims 1-3	1,12,14, 20,26
X	DE 42 22 870 A (ABB RESEARCH LTD) 13 January 1994 see column 2, line 60 - column 3, line 6; claim 1; figure 1	1,2,12, 20,26

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
10 February 1999	17/02/1999

Name and mailing address of the ISA	Authorized officer
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INTERNATIONAL SEARCH REPORT

In' ational Application No
PCT/GB 98/03670

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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	see page 8, line 1 - page 9, line 8 see page 12, line 17 - line 22	
X	see page 13, line 9 - line 12; claims 1-3,11,13,15,17; figures 1,2 ---	34
A	DE 598 948 C (SIEMENS-SCHUCKERTWERKE) 21 June 1934	1,12,19, 20,26, 32,33
X	see page 2, column 2, line 80 - page 3, column 1, line 8; claims 1-3; figure 3 ---	37,38
A	DE 940 341 C (METALLGESELLSCHAFT) 15 March 1956 see page 2, line 93 - line 126; claim 1; figure 1 -----	1,12-16

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